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ESTIMATION OF GROUNDWATER POTENTIAL USING SURFICIAL RESISTIVITY MEASUREMENTS: A CASE STUDY FROM PARTS OF MAKURDI BENUE STATE NIGERIA

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ABSTRACT

A geophysical survey involving vertical electrical sounding (VES) was carried out at Makurdi, Benue State Capital which is in the North Central of Nigeria using Schlumberger electrode array. The results show that the area is characterized by 4–5 geoelectric subsurface layers. The measured aquifer thickness ranges from 6 to 69 m, with an average value of 36.7 m and the aquifer resistivity ranges from 7 to 378 Ωm with an average of 133.8 Ωm. The aquifer thickness and aquifer resistivity were used to compute the values of the hydraulic conductivity and transmissivity. The aquifer thickness and aquifer resistivity along side with the estimated hydraulic conductivity and Transmissivity were used as indices for evaluation of groundwater potentials. The groundwater productivity potential in the area has been classified into two zones namely; high and intermediate. This study has revealed that no single index determines the groundwater productivity potential but a combination of two or more factors.

KEYWORDS: Vertical electrical sounding, groundwater potentials, aquifer resistivity, hydraulic conductivity transmissivity and Makurdi.

INTRODUCTION

Surface water was the major source of drinkable water since the beginning of mankind or since creation and because of population growth and economic development, surface water in many parts of the world are pushed to their natural limits. Unfortunately, surface water reservoirs which are historically safer and cheaper than groundwater as major potable water resources, have not been properly recharged and maintained to meet the population's need. Hence, the search for groundwater which is strategically valuable because of its high quality and availability as it represents about 97% of the planet's fresh water (Singh et al., 2006).

Electrical resistivity survey, a geophysical survey technique has proved to be an effective and a reliable tool in locating viable aquifers for continuous and regular water supply (Todd and Mays, 2005). This method has the advantage of non-destructive effect on the environment, cost effective, rapid and quick survey time and less ambiguity interpretations of results when compared to other geophysical survey methods (Todd, 1980).

Correlations between hydraulic and geoelectric parameters have been studied by many authors (Kelly, 1977; Onuoha and Mbazi, 1988; Niwas and Singhal, 1981). These correlations are important because empirical/semi-empirical relations derived from such relationships could be used to extrapolate aquifer parameters using surface resistivity measurements. Unfortunately, the conventional methods for the determination of hydraulic parameters such as pumping tests, permeameter measurements and grain size analysis are invasive, relatively expensive and either integrate over a largest volume of data or provide information only to a small section of the aquifer in the vicinity of the borehole (Mendosa et al.,2003 and Niwas et al.,2011). For these reasons, empirical/semi-empirical relations of estimating the spatial distribution of aquifer parameters such as hydraulic conductivity, transmissivity and aquifer depth are necessary.

DESCRIPTION AND GEOLOGY OF THE AREA

Makurdi, the Benue State Capital in the North Central of Nigeria is located between latitudes 7°68'N and 7°79'N and longitudes 8° 49'E and 8° 62'E (Figure 1), and covers an approximate area of about 520 square kilometres. The study area is situated in the Guinea Savanah vegetation zone. Annual rainfall in Makurdi town is consistently high, with an average annual total of approximately 1173 mm (Abah, 2012) which ranges from 775 to1792 mm. Temperature is generally high in this area. The rainy season lasts from April to October, with 5 months of dry season (November to March). In January, the lowest temperatures of about 26^{0}C are usually recorded while the highest of about 32^{0}C are recorded in March / April.

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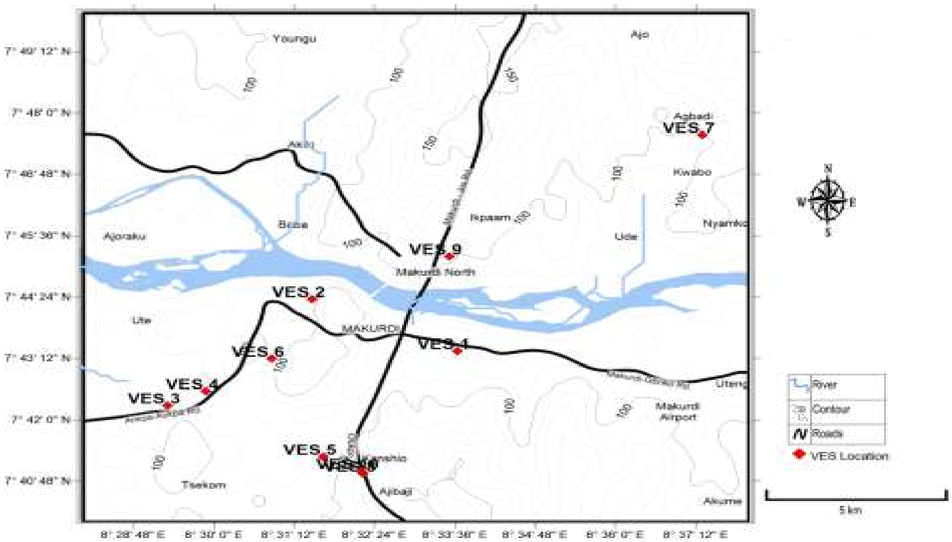


Figure 1: Topographic Map of the study area showing the location of VES locations

The study area is underlain by the Makurdi Formation (Figure 2), which comprises of the lower Makurdi Sandstone: the upper Makurdi Sandstone and the Wadata limestone (Nwajide, 1982). The lower Makurdi Sandstone, which could be found around the Makurdi Airport, consists of sandstones and mudrocks. They are micaceous throughout with mudrocks predominating. The upper Makurdi sandstone is similar to the lower Sandstone but with mudsrocks being relatively less common, as found around the North Bank area of Makurdi. Sandstones and shales outcrop prominently and the sandstone range from very fine to medium in grain size. In this zone, there are shale units of mainly fissile siltstone, usually brownish grey in colour and often abundantly micaceous. Wadata limestone also consists of several limestone occurrences; most outcrops are shelly limestone often closely associated with mudrocks which is the most extensive member of the Makurdi Formation (Nwajide, 1982). The Sandstones in this zone are generally fine to medium grained, moderately sorted, micaceous and feldsphatic. In some parts, they are calcareous, micaceous and shelly. Various types of cement like iron oxides, silica, carbonates and clay were shown to be present in the Makurdi Sandstone, thus making groundwater flow less effective.

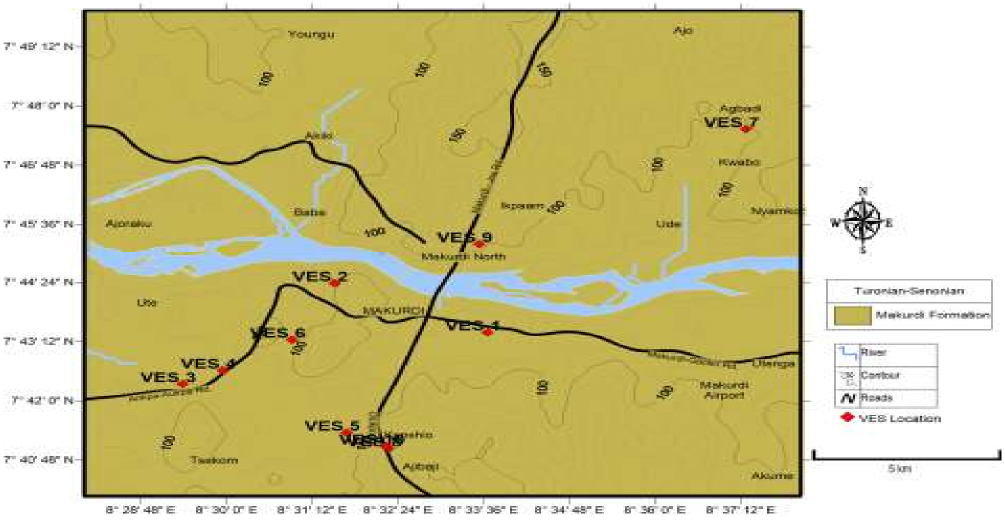


Figure 2: Geologic map of the study area.

Data Acquisition and Method

Ten (10) vertical electrical sounding (VES) points were carried out in different locations within the study area using PZ-02 resistivity meter. The Arrangement of the electrode configuration was Schlumberger with Maximum half current electrode spacing (AB/2) of 100.0m and potential electrode spacing (MN/2) of 15.0m. The apparent resistivity was computed using equation (1);

$$\rho_a = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right)\frac{\Delta V}{I} \quad \text{-------------------------------} \quad (1)$$

Where ρ_a is the apparent resistivity, π is $\frac{22}{7}$, $G = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right)$ is geometrical factor, and $\frac{\Delta V}{I} = R$, is the resistance.

The apparent resistivity values obtained from equation (1) were plotted on bi-log graph against the half current electrode separation spacing. From these plots, qualitative deductions, such as the resistivity of the first or top layer, the depth of each layer, and the curve signatures or types were made. The initial quantitative interpretations were made using partial curve matching technique, in which the field curves produced or generated were matched segment by segment with the appropriate master curves and auxiliary curves. The resistivities and thicknesses of the various layers were improved upon by employing an automatic iterative computer program following the main ideas of Zohdy and Martin (1993). The WINRESIST computer software was employed for carrying out the iteration and inversion processes.

The hydraulic conductivity was estimated using the equation as given by Heigold et al. (1979):

$$K = 386.40 R_{rw}^{-0.93283} \quad \text{---------------------------------} \quad (2)$$

Where, K is the hydraulic conductivity and R_{rw} is the aquifer resistivity.

The transmissivity values were calculated using (Todd, 1980):

$$T = Kh \quad \text{--} \quad (3)$$

Where, T is transmissivity, K is hydraulic conductivity and h is aquifer thickness. This provides a general idea of the water producing capabilities of aquifer from surficial electrical methods.

The total longitudinal conductance S_T of the overburden unit at each vertical electrical sounding station was obtained from the mathematical relation (Zohdy et al., 1974):

$$S_T = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \quad \text{--} \quad (4)$$

where S_T = total longitudinal conductance of the overburden, ρ_i = layer resistivity, h_i = layer thickness, and *n* = number of layers and were used to characterize the aquifer protective capacity of the area.

The longitudinal conductance (S) was calculated thus:

$$S = \frac{h}{\rho} \quad \text{---} \quad (5)$$

Where, h is layer thickness of the aquifer and ρ is layer resistivity of the aquifer.

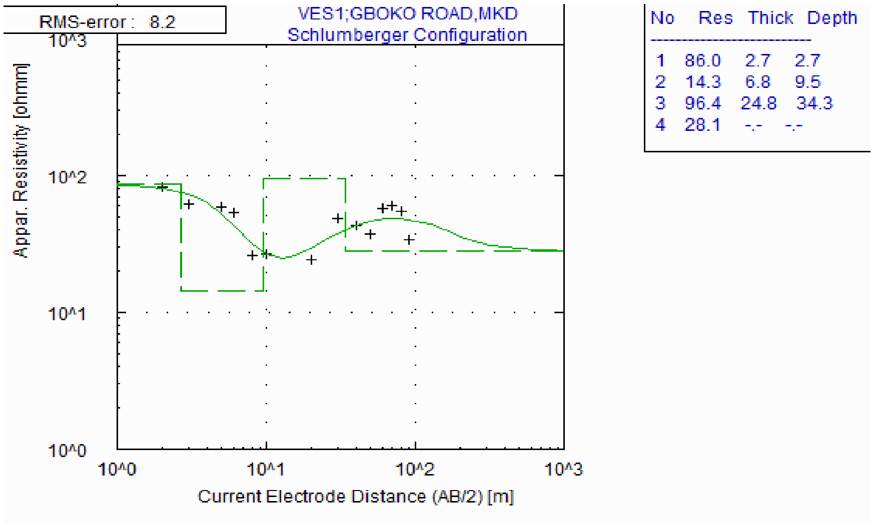
RESULT AND DISCUSSION

The summary of the interpreted electrical resistivity survey is presented in Table 1. The VES analysis reveals that the area is characterized by 4 – to 5-geoelectric subsurface layers with 4 - layer type occurring more.

Table 1: Summary of the VES analysis.

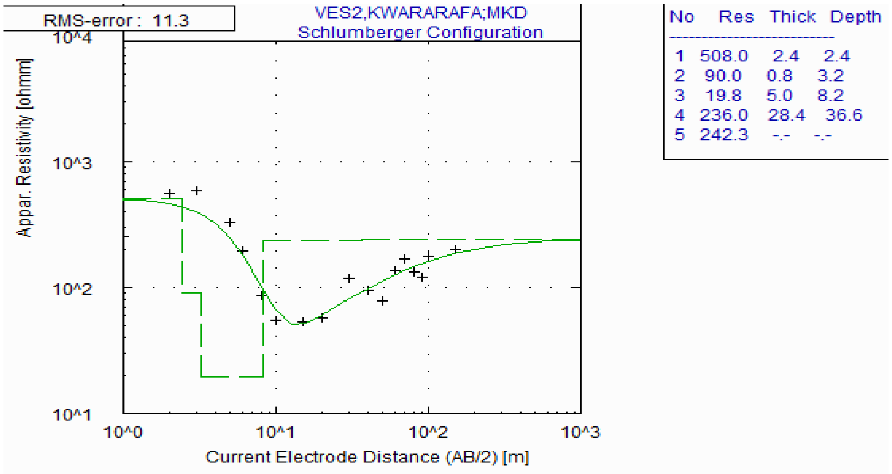
VES Station	Location Name	Aquifer Resistivity	Aquifer Thickness	Longitudinal Conductance	Hydraulic Conductance	Transmissivity	Latitude	Longitude	Curve Type	Groundwater Potential
1	Gboko Road, MKD	111	32	0.28828	4.78	152.96	7.72241	8.56058	HK	High
2	Kwararafa, MKD	256	29	0.11328	2.19	63.51	7.73935	8.52446	QHA	Intermediate
3	Industrial Estate, MKD	176	69	0.39205	3.11	214.59	7.70466	8.48856	AK	High
4	Fed Low Cost Nika RD, MKD	79	7.0	0.08861	6.56	45.92	7.70932	8.49805	HA	Itermediate
5	New Kanshio Layout, MKD	80	78	0.78006	5.26	410.28	7.68794	8.52730	QHA	High
6	David Mark Bye-Pass, MKD	98	22	0.22357	5.36	117.92	7.71989	8.51439	HKH	High
7	U.A.M	75	57	0.76000	6.89	372.73	7.79285	8.62162	HAA	High
8	Kanshio MKD	27	6.0	0.22222	17.86	107.16	7.68247	8.53725	HA	High
9	North Bank MKD	58	40	0.68966	8.75	350	7.75326	8.55861	HK	High
10	Kanshio MKD	378	27	0.07143	1.52	41.04	7.68336	8.53665	QH	Intermediate
	AVERAGE	133.8	36.7	0.36291	6.228	189.611				

The curve types obtained from the study area are HK, QHA, AK, HA, QHK, HAA and QH. The 4 – layer geoelectric section is characterized by HK, AK, HA and QH. (Figures 3, 5, 6 and 9). The 5- layer geoelectric section is characterized by QHA, QHK, and HAA. (Figures 4, 7 and 8).



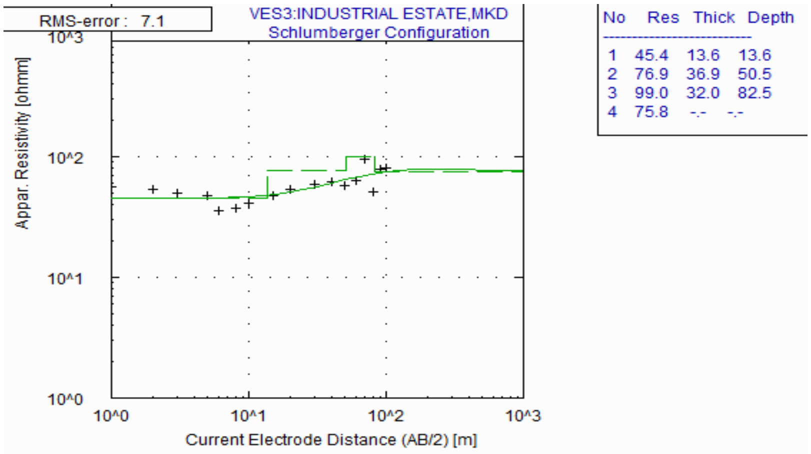
No	Res	Thick	Depth
1	86.0	2.7	2.7
2	14.3	6.8	9.5
3	96.4	24.8	34.3
4	28.1	-.-	-.-

Figure 3: Typical HK curve type.



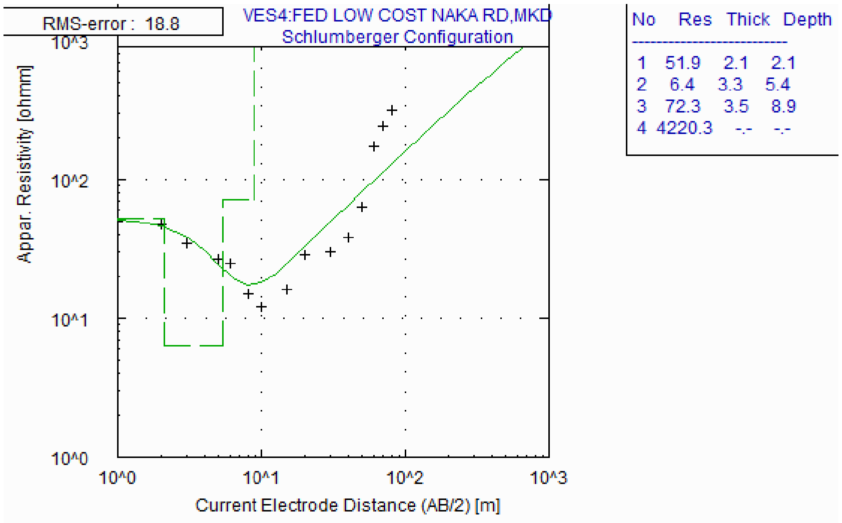
No	Res	Thick	Depth
1	508.0	2.4	2.4
2	90.0	0.8	3.2
3	19.8	5.0	8.2
4	236.0	28.4	36.6
5	242.3	-.-	-.-

Figure 4: Typical QHA curve type.



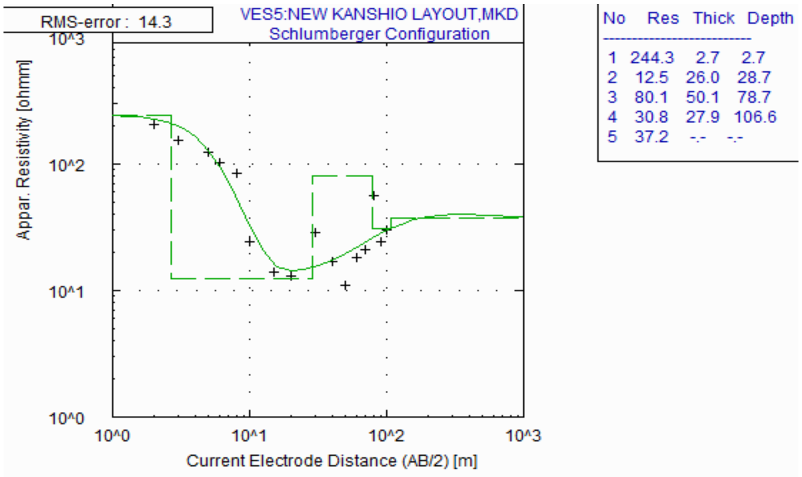
No	Res	Thick	Depth
1	45.4	13.6	13.6
2	76.9	36.9	50.5
3	99.0	32.0	82.5
4	75.8	-.-	-.-

Figure 5: Typical AK curve type.



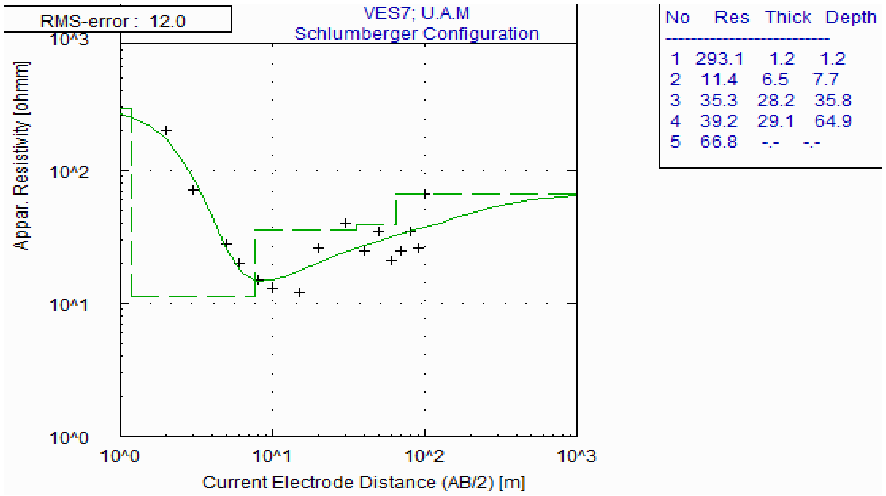
No	Res	Thick	Depth
1	51.9	2.1	2.1
2	6.4	3.3	5.4
3	72.3	3.5	8.9
4	4220.3	-.-	-.-

Figure 6: Typical HA curve type.



No	Res	Thick	Depth
1	244.3	2.7	2.7
2	12.5	26.0	28.7
3	80.1	50.1	78.7
4	30.8	27.9	106.6
5	37.2	-.-	-.-

Figure 7: Typical QHK curve type.



No	Res	Thick	Depth
1	293.1	1.2	1.2
2	11.4	6.5	7.7
3	35.3	28.2	35.8
4	39.2	29.1	64.9
5	66.8	-.-	-.-

Figure 8: Typical HAA curve type.

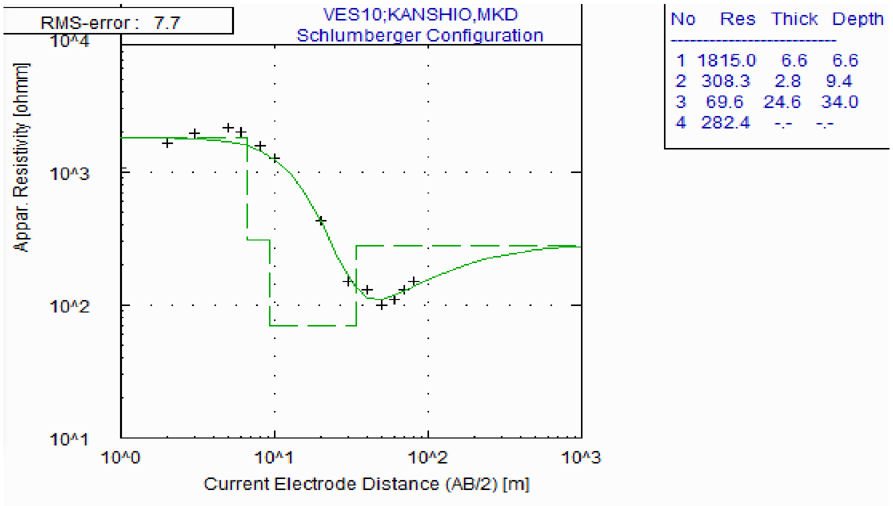


Figure 9: Typical QH curve type.

Table 1 shows the variation of aquifer resistivity and thickness due to lithologic composition, from which the longitudinal conductance, hydraulic conductivity and transmissivity were computed. The aquifer resistivity in the study area ranges from 25 to 378 Ωm with an average of 133.8 Ωm in which the minimum resistivity is observed in point VES 8, and a maximum resistivity is observed in point VES 10. It also shows the variation of the thickness in the study area in which the minimum value is observed in point VES 4 and a maximum value in point VES 3 with the average of 36.7m. The groundwater potentials of the area are evaluated based on the following indices; Dar Zarrouk parameters (Aquifer resistivity, Aquifer thickness and longitudinal conductance), hydraulic conductivity and Transmissivity.

Table 1 was used to draw 2D contour maps for all the groundwater potential indices used in the VES analysis. Figure 10 shows the spatial distribution of aquifer resistivity in the study area in which the highest value is observed at VES 10 and the lowest at VES 8. This suggests that zones with low aquifer resistivity values will have high conductive geomaterials, such as poor groundwater quality. Figure 11 shows the spatial distribution of aquifer thickness across the study area. It is observed that the aquifer thickness decreases from the northern part to the southern part of the study area and from the eastern part to the western part of the study area. Figure 12 shows the spatial distribution of Hydraulic conductivity across the study area. Low Hydraulic conductivity is observed in some parts while high hydraulic conductivity is observed in most parts of the study area. Hydraulic conductivity is proportional to effective permeability. Permeability is also fundamental important in aquifer studies and in determining contaminant flow behaviour in the subsurface. It also determines the rate at which water is able to flow into and through porous storage rocks in aquifers (Kelvin Hefferan and John O'Brien, 2010), Areas with high hydraulic conductivity are most likely to have good aquifer recharge quality/capability. Figure 13 shows that high trasmissivity is observed at southern part and some western part of the study area. For characterization of rocks as a water conductivity media, transmissivity is a major property (Fatoba et al, 2014). It can be deduced that groundwater flow potential increases as transmissivity and permeability (Hydraulic conductivity) increases. In order to categorize the groundwater potentials of the area, standards for transmissivity (Krasny,1993) was employed (Table 2).

Table 2: Standards for transmissivity (after Krasny, 1993)

Transmissivity (m^2/day)	Designation	Groundwater supply potentials
≥1000	Very high	Withdrawal of great regional importance
100 – 1000	High	Withdrawal of lesser regional importance
10 -100	Intermediate	Withdrawal of local water supply (small community, plants, etc.)
1 10	Low	Smaller withdrawal for local water supply (private consumption)
0.1 -1	Very low	Withdrawal for local water supply (private consumption)
< 0.1	Impermeable	Sources for local water supply are difficult

The high groundwater of potential is observed at VES 1, 3, 5, 7 and 9 because of the high values of Hydraulic conductivity, transmissivity and aquifer thickness with low aquifer resistivity. These VES points are zones of high water bearing potential which is most likely to be of great regional importance. The low groundwater potential is observed at VES 2, 4, 6, 8 and 10 due to the high value of aquifer resistivity and low value of the aquifer thickness though some VES stations have high value of Transmissivity and Hydraulic conductivity. These zones are most likely to provide local water supply for private consumption.

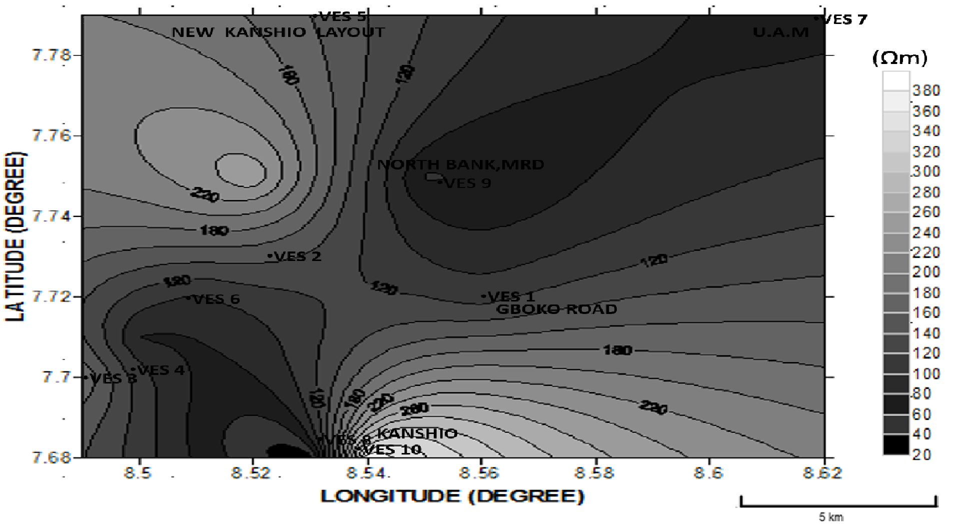


Figure 10: Spatial distribution of Aquifer resistivity in the study area.

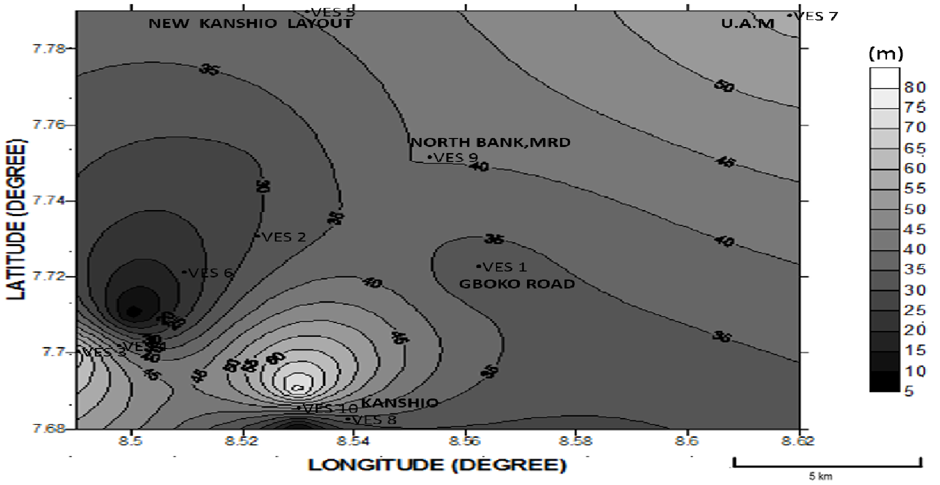


Figure 11: Spatial distribution of Aquifer thickness in the study area.

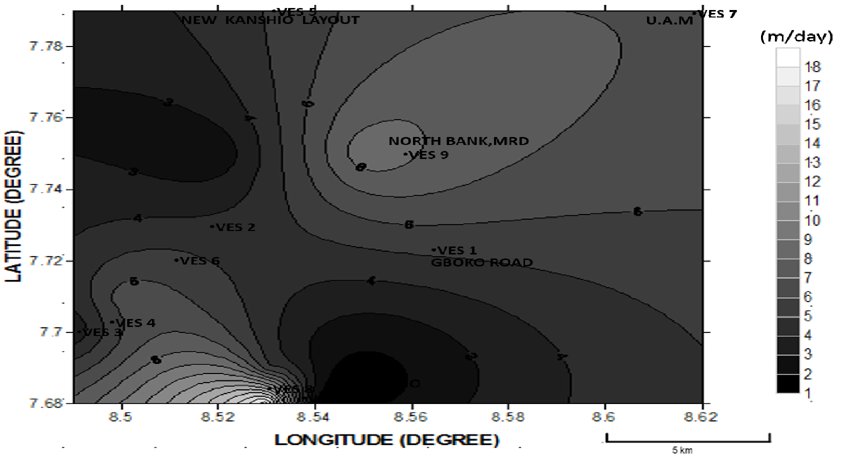


Figure 12: Spatial distribution of Hydraulic conductivity in the study area.

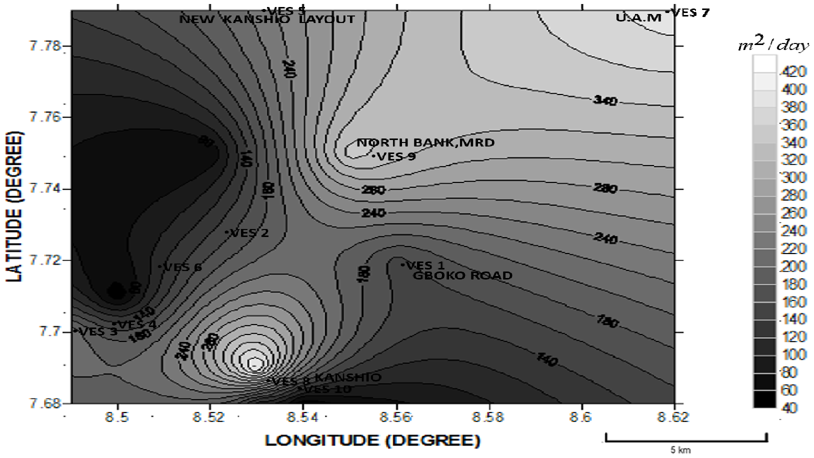


Figure 13: Spatial distribution of Transmissivity in the study area.

CONCLUSION

The Ten (10) Vertical Electrical Soundings (VES) carried out in Makurdi, Benue State has been used to compute the aquifer hydraulic conductivity and the transmissivity of the survey area. A standard transmissivity model was used to categorize the groundwater potentials of the study area. The zone with the lowest hydraulic conductivity (1.52m/day) has the lowest transmissivity (41.04m/day) which gives the lowest groundwater potential. The emperical relationship established between hydraulic conductivity and aquifer resistivity is a good tool for categorizing groundwater potential. Therefore, geoelectrical sounding technique is an inexpensive tool for calculating the hydraulic parameters and categorizing the aquifer potential of the study area.

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